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OAR RESEARCH REVIEW

VOLUME VII NUMBER 2 FEBRUARY 1968

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ON THE COVER:

AFCRL is the largest developer and user of large plastic balloons in the United States--and has been so for the past decade. Each year AFCRL launch crews send aloft an average of 150 large balloons carrying payloads sometimes measured in tons to altitudes of between 70,000 and 130,000 feet.

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JACOB SEIDEN *Editor*

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gamma radiation from celestial sources

DR. R. C. HAYMES
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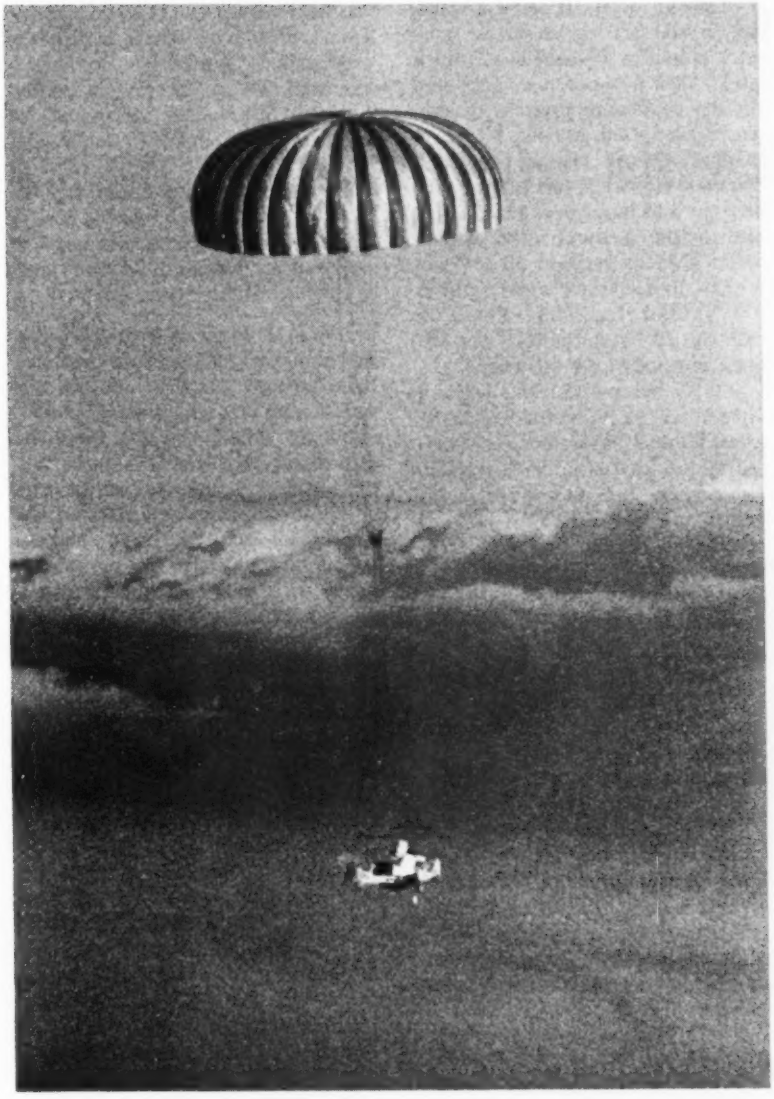

Figure 1.—The 620-pound gondola descending on a 64-foot parachute after an 8-hour float at 130,000 feet over Texas. The gondola automatically points the gamma-ray detector at a celestial source.

There are objects in the universe that apparently generate huge amounts of energy through some presently unknown process. For example, the most powerful of these discrete sources may have developed on the order of 10^{62} ergs (10^{62} ergs is the amount of energy that would be liberated by the annihilation of 100 million solar masses). It therefore appears that nature has found some means of generating energy that is far more effective than any technique now known to us.

In an effort to clarify the nature of the process involved, the Nuclear Physics Division, Directorate of Physical Sciences, AFOSR, has been supporting a group at Rice University that has undertaken a search for gamma rays from some of these objects. Depending on the nature of the object in question, various theories predict that gamma radiation with energies up to ~ 600 keV should emanate from them.

The synthesis of heavy elements is believed to take place in some of these explosive events; the radioactivity of these elements would produce a complex spectrum of gamma-ray lines. (1) The annihilation of matter by antimatter would lead to a line at 511 keV. (2) Radiation from hyperrelativistic electrons in a magnetic field in the object should cause gamma rays through the synchrotron process, leading to a continuum spectrum, most likely of a power-law shape. (3) Bremsstrahlung by electrons at temperatures in excess of 10^8 °K would also produce a continuum, but, in that case, an exponential energy spectrum is more probable. The primary energy source is still unidentified for these last two processes; but gravitational collapse of huge masses and the emissions of the hypothetical neutron star have been mentioned as possibilities.

Gamma radiation of any type had not been observed from objects beyond the solar system. The Rice group, however, has now discovered two such gamma-ray sources with a balloon-borne instrument.

The "gamma-ray telescope" developed at Rice is a directional scintillation counter employing a 12"-long x

10″-diameter NaI(Tl) crystal. This large crystal acts as an active collimator around a 4″-diameter, 2″-thick NaI(Tl) that is buried in a well bored into the collimating crystal. An anticoincidence system provides 4π active shielding against charged particles; pulses due to photons are analyzed for energy by a balloon-borne 128-channel pulse height analyzer. The system accepts photons between 30 keV and 560 keV of energy, or wavelengths as short as 0.02 angstroms. Fluxes as small as 10^{-5} photons/cm^2-sec-keV can be detected by the "telescope."

The "telescope" tracks a celestial source in its diurnal motion across the sky with a pointing system also developed by the Rice group. (The gondola is shown in the photograph as it returned to earth in far West Texas.) The pointing accuracy of the system has been measured in flight as $\pm 1°$. The background is measured by pointing away from the source every 10 minutes.

The two gamma-ray sources were discovered in flights conducted during the summer of 1967 from the Scientific Balloon Flight Station of the National Center for Atmospheric Research at Palestine, Texas. (The first flight took place on 4 June.) The telescope was aimed at the Crab Nebula, the remnants of the stellar explosion observed in broad daylight in the year 1054. A relatively bright continuum gamma spectrum has been found; a power-law differential spectrum of the form (7.1 ± 2.8) $E^{-2.19 \pm .08}$ [photons cm^{-2}sec^{-1}keV^{-1}] was noticed at all energies observed, up to 560 keV. The Rice group finds that there are several consequences of this, if the spectrum is indeed due to the synchrotron process. A magnetic field of 2×10^{-4} gauss is present in the Crab, and the 560-keV radiation is due to electrons with 2×10^{14}eV of energy (320 ergs). Electrons spiral about the magnetic-field lines; the radius of gyration of a 2×10^{14}eV electron in the Crab's field would be about 5 times the radius of Pluto's orbit about the sun. (Electrons of even these energies need over a week to complete just one orbit.) The output power of the Crab, integrated over all wavelengths down to .02 angstroms, is about 50 times the input power that has been calculated (1) to be available from radioactivity, on the basis of the Californium hypothesis of nucleosynthesis. The gamma-ray observation has also upset ideas concerning the energy balance in the Crab. Previous estimates were that there were about 10^{48}ergs in relativistic electrons in the Crab, or about the same as the present kinetic energy of the expanding gas. It now appears, however, that there are 5×10^{49}ergs in the relativistic electrons.

The other source of gamma radiation thus far found is in the constellation Cygnus. A continuum was observed from this source also, but of a decidedly different shape from the spectrum of the Crab's gamma radiation. While it is brighter than the Crab at the lower energies, it is about the same intensity at 400 keV, and no radiation was detected at energies in excess of 453 keV. Hence, there is a decided break in the spectrum at energies around 140-150 keV. The gamma-ray spectrum can be fit with an exponential of the form $(0.21 \pm .01)$ $e^{-E/101 \pm 7}$ keV/cm^2-sec-keV. The equivalent temperature of the 101-keV electrons would be 1.2 billion degrees (absolute), well into the thermonuclear domain of temperatures.

An equally valid fit, however, is made by 2 power-law spectra. The power-law valid between 35 keV and 123 keV, $(1.50 \pm .23)E^{-1.64 \pm .04}$ [photons/cm^2-sec-keV], fits well with the spectrum of X radiation detected by other investigators. (4) The gamma-radiation spectrum valid between 152 and 453 keV is $(7.9 \pm 7.1) \times 10^3 E^{-3.38 \pm .17}$ in the same units. The break in slope is apparent.

The Cygnus source is one of the most puzzling enigmas in the skies. It has not been seen in the optical, and is also apparently radio-quiet; but it emits even more gamma-ray energy than the Crab. The Crab, of course, is one of the brightest radio sources in the sky. Although one would like to believe that the same mechanisms operate in both sources, the Crab and Cygnus seem to be quite different.

It is still possible, however, that Cygnus and the Crab are members of the same class of sources. Conceivably, the process that causes the observed break in the Crab spectrum in the optical region ($E \sim 1$ eV) is the same as that causing the break in the Cygnus spectrum at $\sim$ 150 keV. If both spectra are indeed due to the synchrotron process, this would suggest that the Cygnus source is much younger than the Crab, and radio emission may yet be observed from Cygnus as the object ages. Of course, the gamma radiation could be caused by some as-yet-unknown process. Further observations of celestial sources may introduce a pattern so that some conclusions may be drawn.

The Rice group is continuing its investigations. The peculiar galaxy M87 has beem measured, although the results are not yet available. M87 is peculiar in that a curious knotted "jet" is observed to emanate from its nucleus; it is as though M87 has exploded. Preparations are under way for some southern-hemisphere observations, to be conducted from Australia. Some of the unusual objects can only be seen in the southern skies.

In conclusion, the discovery of gamma radiation from celestial sources by the group at Rice has thus far created more problems than it has solved in our understanding of high-energy cosmic events. It is hoped, however, that additional observations in this wavelength region will bring some order to the present rather chaotic situation.

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Dr. Robert C. Haymes is presently Associate Professor of Space Science at Rice University, Houston, Texas. He came to Rice University in 1964 from the California Institute of Technology's Jet Propulsion Laboratory where he had been a resident research appointee. He had previously studied at New York University where he received his B.S. in 1952, his M.S. in 1953, and his Ph.D. in 1959, all in Physics. Following that, he became Assistant Professor of Physics at NYU until 1962.

Dr. Haymes is a member of Sigma Xi, Sigma Pi Sigma, the American Astronomical Society, the American Geophysical Union, and the American Physical Society. His research interests include nuclear astronomy and ionospheric currents.

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anatomy of the system-user interface

Although it does not appear in *Webster's Third New International Dictionary*, 1961 edition, the technical term, "information system," has gained wide use in the past 10 years. It is a common term in management, military, legal, and scientific circles. Does this term convey a new concept? Certainly not, since libraries function as information systems, and so do people. In its technical sense, however, the term has come to be associated with large computer installations and large data and document storehouses.

Webster's states that information involves "the communication or reception of knowledge or intelligence." (1) Thus an information system should communicate and its clients should receive knowledge or intelligence.

A review of several information systems suggests that these systems are falling short in the task of communication, and that their users are not receiving what they consider to be knowledge or intelligence. (2) Among the complex causes underlying these inadequacies are manpower shortages, faulty system designs, and poor publicity. One cause, a subtle one that does not arise from the systems *per se* or even from the receivers *per se*, lies in the realm of "interface." Interface denotes the relationship between the system and its user or client–the system-client "rapport" that enables the system to communicate what the client wants to receive.

The system-user interface is an area of current research interest to AFOSR's Directorate of Information Sciences. It is an elusive subject. It can't be pointed to as a part of a whirring, humming assemblage of machines. It can't be seen in a perusal of book shelves and tape libraries. It is not evident in an end product called "result of search." In flow diagrams it may appear as a line pointing to a box labeled "output." It comes into being only when an answer is sought to a specific question.

"Restructuring the obvious" is the way Professor Robert S. Taylor of Lehigh University characterizes the content of his final report (3) prepared under an AFOSR grant for study of the man-system interface in library retrieval. Prof. Taylor recorded interviews with librarians and information specialists in which they described how, from dialogues with clients, they determined the kind of information their clients wanted them to find. He also had a group of undergraduate students record their decision-making and search strategies as they undertook to satisfy self-generated information needs. Prof. Taylor used the two sets of records that resulted as data bases for analyzing two aspects of the interface problem that he calls "negotiating the question" and the "self-help process."

Taylor looks at inquiry as a problem in perception. Preliminarily, there is "an area of doubt in which the question is open-ended, negotiable, and dynamic." A person frequently proceeds through several levels of awareness and definitiveness in formulating an inquiry. He may first experience what Taylor calls a "visceral need," lacking in concreteness and partially inexpressible linguistically. The first attempt at expression may be rambling and ambiguous and may require discussion with colleagues for clarification. A formal, concrete statement of need develops next. Finally, this statement is translated into terms to which the information system can respond. Actually, the client may interrogate the information system from each of these levels of perception.

Taylor finds that librarians and information specialists (and, by extrapolation, information systems) serve best when they have four types of input from the user:

1. Clarification of the subject of the inquiry. One recorded view from behind the reference desk, abbreviated here, offers this example:

> "X said he was interested in 'contact terminals.' I asked him 'Do you mean the type of spring terminals that are used in jacks, plugs and jacks?' He said 'No' and said something about 'binding terminals.' ..... He replied, 'No, that's where the contact comes in, I mean the wrapped type.' So after a few exchanges like that, I got a picture in my mind as to what he was talking about."

2. A statement of why the user wants the information and what he is going to use it for. One interviewee commented:

> "I often learn that in trying to tell me why he needs the information, he clarifies in his own mind what he needs and will then reform his query with a better understanding of his own need."

Taylor notes that "Inquirers frequently cannot define what they want, but they can discuss why they need it. Consequently, they are inclined to ask very specific questions, as if they were ashamed to hold up their ignorance for everyone to see. These may include an innocent request for a directory address which develops into a search on molds; a request for a copy of *Aviation Week* which turns into a basic and broad company proposal on commercial aviation; an inquiry to verify if there is a place called P_____ which turns into a search for information on rat repellents."

3. Personal information about the client, his status, degree of knowledge, familiarity with information resources, an indication of urgency and other environmental factors.

4. An indication of the kind of response the client is willing to accept. In negotiation, Taylor finds, the

> "–image is altered as the inquirer changes his question in response to feedback, as he becomes aware of the capabilities of both the library and the librarian, as he changes his search strategy in the negotiation process, and as he is forced in the netotiation process to place limits of time and size on his inquiry."

A *sine qua non* for information retrieval, of course, is the librarian's expertise in translating the negotiated inquiry into the terms of the information system and, if need be, retranslating the system's response into terms acceptable to the client.

In the self-help experiments, which sought to impart information-seeking habits as well as to elicit data, all the undergraduate subjects asked human intermediaries for guidance. Though they used such tools as catalogs and classification schedules in their searches, none of the undergraduates thought in terms of search strategy. The experiments highlighted the "noise" that exists in catalog structures, and showed that the librarian's tools, in their present form, may have little relevance for the client. Taylor remarks: "The inquirer is only concerned with getting an answer, not with system niceties."

A system is as good as the use that can be made of it by the clients for whom it is designed. Taylor studied phenomena of real systems, not automated ones in research phases. He comments on the potential of films, microforms, and computer media for sophisticated data manipulation and display. The message of his report, however, is the need to better understand the perceptual process–how the human arrives at, and can be helped to arrive at, the information he wants. Taylor also suggests that a new role is emerging for humans in information systems to serve as "interpreters and guides, developing both negotiation skills and displays for users of all levels." In technology transfer, military operations, and other activities, we recognize the significance of information available at the right time in the right place. (4) Full exploitation of the information that we have and that we continue to generate depends upon our ability to organize it properly for processing by men and machines. These are goals of information-sciences research, to which the Taylor report has made a contribution.

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OPOS

study of the Optical Properties of Orbiting Satellites

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The spectacular and exceedingly regular changes in the brightness of the early Soviet upper-stage rockets were of common knowledge to the most casual observers of satellites in mid-1958. Equally familiar today is the nearly invariant brightness of the more recent, large Echo balloon satellites. Less commonly observed were unique instances when the brightness of the Sputnik III rocket, 1958 Delta I, was apparently invariant for long arcs across the sky even though its lazy rotation at approximately 3 rev/min about its center of mass was still present. The apparent invariance was due to special geometrical conditions when the amount of sunlight scattered by the elongated cylindrical form of the rocket was nearly constant in the observer's direction despite the rotational motions.

This unusual behavior of the brightness of early satellites, and many other phenomena observed through small telescopes in the course of optical-tracking experiments at ARL, have raised many fundamental questions on the brightness properties of satellites scattering the intense radiation of the sun. What is the dependence of the brightness on phase angle (see Figure 1) to the illuminating sun? What is the dependence on satellite shape, on the nature of the surface finish, on the size, and on the curvature of the reflecting elements? What secular changes in brightness occur due to exposure to the space environment? With applications in mind, one can ask: What are the rates of change of the brightness of orbiting targets when the control of camera shutters might be required to keep the effective exposure within the dynamic range of the film or photoelectronic detector? What excursions of brightness about a mean brightness level should be anticipated in order to allow evaluation of the performance of automatic space-surveillance systems operating at visible wave lengths? Can relationships be found in the pattern of light variations which would characterize a given type of spacecraft

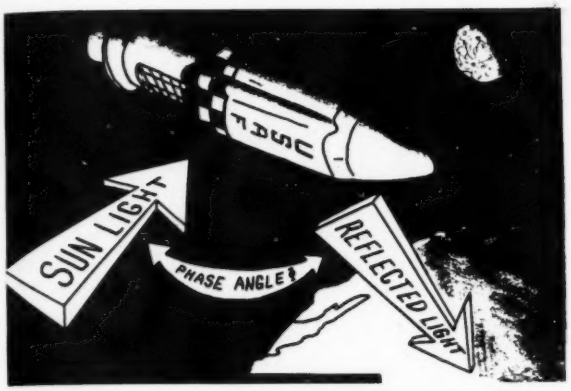

Figure 1.—Scattering of sunlight by an orbiting spacecraft. (Drawing courtesy of E. M. Vallerie, III.)

without requiring the actual resolution of its shape through the atmosphere?

To answer these fundamental physical questions, and to provide a reservoir of data upon which answers to the systems-applications questions can be based, ARL and the Air Force Avionics Laboratory (AFAL) entered a joint research program to conduct photoelectric observations of orbiting spacecraft. This work, begun in 1961, has led to the present ARL program on Optical Properties of Orbiting Satellites (OPOS). In 1962-63, AFAL moved its personnel to New Mexico to bring into operation the Cloudcroft facility. The satellite photometry work was expanded by Messrs. Kenneth E. Kissell and Richard C. Vanderburgh of the General Physics Research Laboratory, ARL.

Figure 2 shows a special multiaxis telescope of 24-inch aperture which was conceived at ARL and placed in operation in 1965, at the ARL Sulphur Grove Field Site near Wright-Patterson Air Force Base, to allow the collection of data from targets at distances up to 25,000 km. This versatile, hand-guided telescope has proven to be of sufficient quality to allow the photographic resolution of low-altitude targets for simultaneous measurement by imaging and nonimaging techniques. The novel 4-axis design allows hand guiding by a skilled observer to better than 30

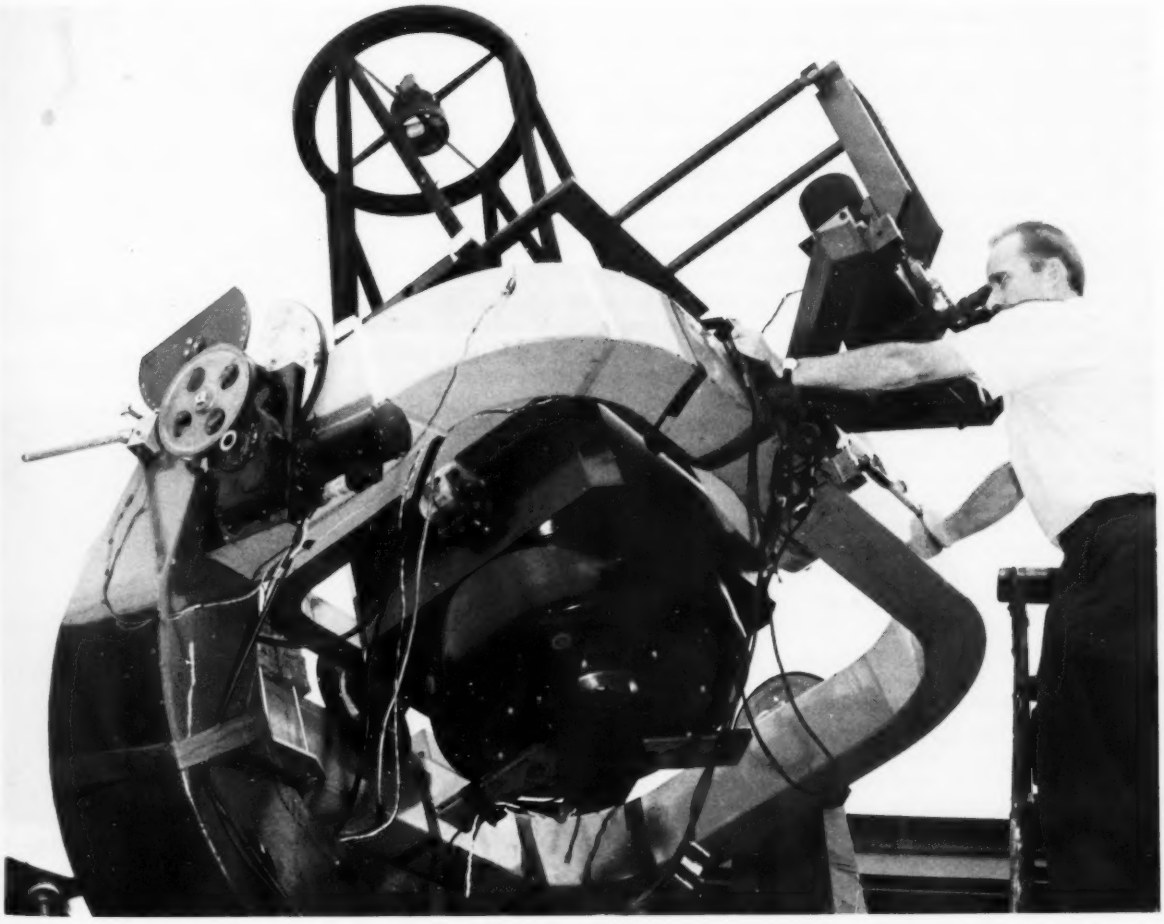

Figure 2.—ARL 4-axis, 24-inch satellite tracking telescope.

arc seconds for most targets.

Nonimaging brightness data are collected by a highly selected photomultiplier utilized in a special logarithmic feedback circuit conceived by Mr. Edmund T. Tyson of AFAL. This highly stable detector system allows measurements of brightness with 10-percent accuracy over a dynamic range of 100,000. This remarkable sensor is not only stable to better than a few percent over this range, but has also allowed resolution of millisecond-duration flashes from active xenon-beacon satellites of the ANNA type. Data are stored in the form of magnetic analog tapes for future analysis.

Optical signatures (light curves, in astronomical parlance) have been collected from over 100 different satellites on more than 500 individual transits. Direct photographs resolving some detail have been obtained on only a few vehicles preparatory to installation of a double-beam tailpiece on the ARL telescope for simultaneous imaging and nonimaging detection. Figure 3 shows an example of the resolution obtainable with direct photography.

Analyses of samples of these data have been made for a wide variety of purposes, in addition to their use in verifying basic theoretical predictions. These diverse applications include: inference of the size and shape of classes of foreign-launched satellites; timing of the xenon-flash discharges on the ANNA B and GEOS A geodetic satellites; measurement of the rotation-rate and orientation changes of various satellites; mapping of the power pattern of the GEOS xenon lamps to attempt the determination of the verticality of the gravity-gradient stabilization system; and the brightness calibration of several high-altitude satellites being used as test targets for the FSR-2 Electro-Optical Surveillance Sensor under development by the Electronic Systems Division, Air Force Systems Command. Work on surface-finish deterioration and polarization effects is now in progress. Several other offices within the Air Force and the National Aeronautics and Space Administration (NASA) are studying the ARL results. NASA has contracted for construction of a modified copy of the ARL 4-axis instrument for space-materials studies.

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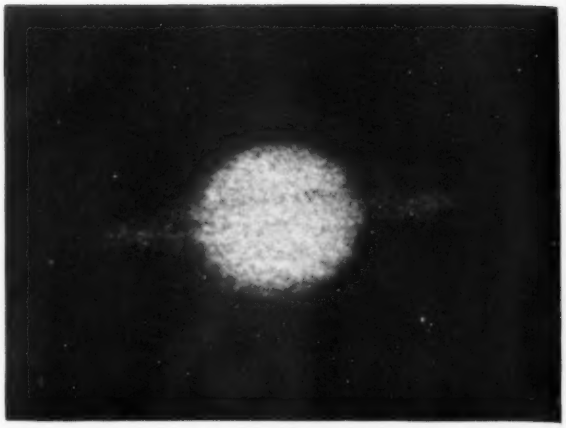

Comparison of satellite images with the planet Saturn at the same scale.

Space object 1451 Proton 8 rocket body slant range 229 KM on 18 September 1965.

Space object 1627 Cosmos 92 rocket body 216 KM slant range on 27 October 1965.

Figure 3.—Examples of direct photographic recording of orbiting spacecraft with the OPOS telescope.

applications of the generalized -function theory

MAJOR JOHN JONES, JR., Directorate of Mathematical Sciences, AFOSR

At the Fall 1966 Meeting of the Society for Industrial and Applied Mathematics, held at the State University of New York at Stony Brook, AFOSR sponsored a symposium on "The Applications of Generalized Functions to Systems Theory." (As used here, "system" refers to any type of physical model, such as an electrical network, a mechanical device, or an interaction between elementary particles.) The purpose of the Meeting was to provide a forum for the discussion of trends and problems in this rapidly growing field of applied research. It also presented an opportunity for scientists, applied mathematicians, and engineers to acquaint themselves with the basic tools and techniques in this area. Both research and expository papers were encouraged, with particular emphasis on the effective use of the generalized-function theory in the study of physical systems. Some of the papers presented appeared in the July 1967 *SIAM Journal on Applied Mathematics.*

In invited papers, Bremermann, de Jager, and Guttinger surveyed various aspects of the general theme. In other papers, Anderson and Newcomb and Dolezal reported important results concerning problems arising from electrical network theory; Beltrami described work in the general area of mathematical systems theory; Guttinger and Pfaffelhuber and Jaffe applied the generalized-function theory to quantum field theory; Liverman related the concept of a distribution to the measurement of a physical variable; and Beltrami and Wohlers and Zemanian reported results concerned with generalized integral transform and their uses which are of importance in applied mathematics and engineering. The generalized-function theory can be developed for functions of several variables, and provides a simple but more complete theory of such topics as Fourier series and integrals, convolutions, and partial differential equations.

An early treatment of the theory of distributions is given in *Theorie des Distributions* by Laurent Schwartz (1). More recent treatments of the subject of generalized functions include the work of A. Zemanian (2), T. P. G. Liverman (3), Beltrami and Wohlers (4), Gelfand and Silov (5), J. Mikusinski (6), M. J. Lighthill (7), A. Friedman (8), and I. Halperin (9).

After the introduction of the operational calculus at the end of the last century, many formulae were used which had not been adequately clarified from the mathematical point of view. One example of such is the Heaviside function, which vanishes for values of x not exceeding zero and is equal to 1 for positive x. It is said that the so-called "derivative" of the Heaviside function is the Dirac delta-function $\delta(x)$, which has the mathematically impossible property of vanishing everywhere except at the origin where its value is such that $\int_{-\infty}^{+\infty} \delta(x)dx = 1$. This "function," and its successive so-called "derivatives,"

have been used with considerable success in obtaining solutions to physical problems.

Following Laurent Schwartz's (1) theory of distributions and J. Mikusinski's (6) operational calculus, there has been a great deal of mathematical research in the various aspects of generalized functions. Most of this research has been of a highly abstract nature. A number of expository articles as well as investigations into simplified approaches to the subject have been written. Until fairly recently, these theories have found comparatively little application in the solution of problems in engineering and physics. Recently a number of research papers have appeared which make use of the full power of the generalized-function theory to solve applied problems. Because the theory of generalized functions has had such an impact on various mathematical disciplines, it appears that it will also be of considerable use in the applied sciences.

Dirac suggested that the "delta-function" could be avoided by using instead a limiting procedure which involved ordinary (mathematically possible) functions. However, the delta-function can be kept and made rigorous by defining it as a measure, that is, a set-function in place of an ordinary point-function. This suggests that the idea of a point-function be enlarged to include new entities, similar to the idea of the rational numbers enlarged by Dedekind to include all real numbers, and the derivative be generalized so that every point-function has a well-defined derivative. These concepts are carried out in the generalized-function theory; the new system of entities, which are called distributions, includes all continuous functions, all Lebesque locally summable functions, and new entities, of which a simple example is the Dirac measure function given above.

The more general process of derivation assigns to every distribution a derivative which is again a distribution, and so every distribution, including every locally summable point-function, has derivatives of all orders. The derivative of a locally summable point-function is always a distribution, although not in general a point-function. However, it coincides with the classical derivative whenever the latter exists and is locally summable.

The theory of distributions establishes a rigorous foundation and validity to such formulae of operational calculus as are mentioned above.

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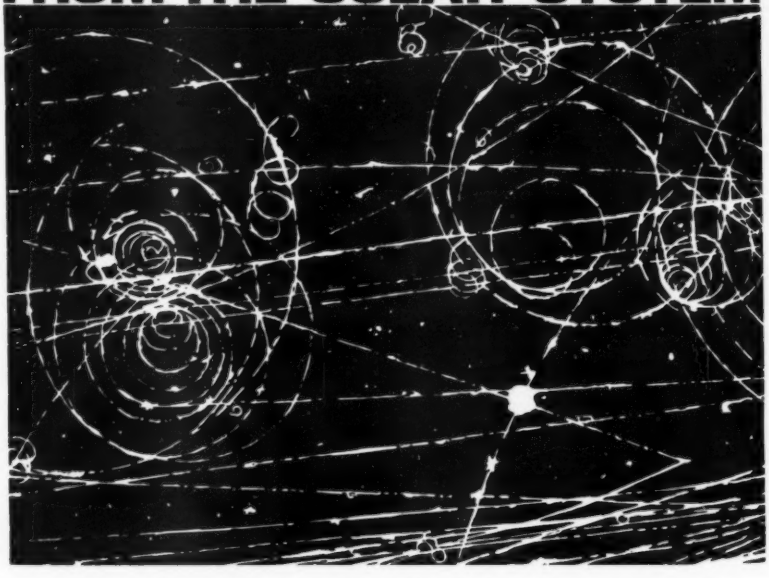
gravitational radiation FROM THE SOLAR SYSTEM



MOSHE CARMELI, General Physics Research Laboratory, ARL

Einstein's general theory of relativity is the best available theory of gravitation and is no doubt the most beautiful theory we now have in physics. Its physical basis is the law of equality of inertial and gravitational masses, which is manifested mathematically by the hypothesis that space and time is Riemannian rather than Minkowskian with its maximal uniformity. The theory has also been verified experimentally by three classical experiments: the gravitational red shift, the deflection of light by the sun, and the precession of the perihelion of the planet Mercury, although

only the latter experiment seems to be a test of the full formalism of relativity. New experiments now being carried out at Stanford, Maryland, and MIT will certainly lead to a better understanding of general relativity and gravitation.

General relativity was developed long before physicists discovered quantum mechanics and the concept of quantum fields. It is therefore not surprising that several physicists have been trying to find alternative theories of gravitation based not on general covariance and Riemannian geometry, but rather on assumptions that are usually accepted in quantum fields. It is argued that, although gravitation was the first force field to be discovered, the logical structure of physics might not necessarily conform to its historical development. Such a theory, recently adduced by S. Weinberg after a careful study of gravitation based on S matrix formalism, was applied by him to derive a formula for the power and spectrum of very long waves of gravitational radiation emitted by the sun. Gravitational radiation by the solar system was subsequently investigated by this author who applied general relativity and obtained the same result as that obtained by Weinberg for the long-waves case. (1)

The following paragraphs constitute a very brief review of a comparison between the two formalisms. For more details see reference (1) where Weinberg's work on the quantum theory of massless particles is cited.

Weinberg assumes fundamentally the Lorentz invariance of the S matrix, along with a few elementary ideas about pole structure. The concept of particle is considered in this approach as more fundamental than that of field. The whole formalism is heavily based on E. Wigner's classification of elementary particles that followed from the theory of representations of the Inhomogeneous Lorentz Group (Poincaré group). Among other particles that were predicted mathematically in Wigner's work of 1939, there are two massless particles of spin one and spin two. These are now assumed to be the quanta of energy associated with the electromagnetic and the gravitational fields, respectively, and are called the photon and the graviton.

It follows that these requirements are enough to imply the equality of the gravitational and the inertial masses of a body, and other properties of gravitation which have been explained previously. Further, by using perturbation theory, i.e., by applying the well-known Feynman-Dyson expanded form of the S matrix, Weinberg believes he has obtained the Einstein field equations for the gravitational field in the Heisenberg representation.

Within this framework, other relevant topics associated with this approach were discussed, such as how to remove the infrared divergences arising in quantum gravidynamics by applying familiar methods used in quantum electrodynamics. Additional divergences appear, however, that have no analog in quantum electrodynamics due to the fact that very long waves of gravitational radiation (in particle terms called soft gravitons) are also emitted from energetic massless particles (neutrinos, photons, and gravitons). This property is characteristic of gravitation and is classically manifested by the nonlinearity of the field equations. It follows that these additional divergences cancel when all Feynman diagrams are summed. Also, it is interesting to point out that this cancellation is a consequence of the conservation law of the gravitational field which follows from the Bianchi identities that the Einstein tensor satisfies. It is not clear whether or not such a cancellation occurs in other theories in which massless particles can emit soft massless particles of spin one (such as the Yang-Mills theory).

As mentioned before, this formalism was applied to calculate scattering processes, and a formula was obtained to estimate the gravitational radiation power in arbitrary collisions, including its spectrum form. General relativity already provides us with formulas for calculating gravitational radiation power if we happen to know the matter distribution (quadrupole moment) and its time dependence, just as we know how to calculate electromagnetic radiation if we know the charge distribution (dipole, quadrupole, ...) and its time dependence. (To obtain the power of radiation as a function of the frequency, one refers to Fourier analysis.) It is well known that, in the spectral distribution of the radiation accompanying a collision, the main part of the intensity is contained in frequencies $\omega \simeq 1/\tau$, where τ is the order of magnitude of the duration of the collision. For this interval of frequencies, however, one cannot obtain a general formula for the distribution. The "tail" of the distribution at low frequencies, satisfying the condition $\omega \tau << 1$ is, however, easier to handle. This is in fact the case discussed by Weinberg through quantum electrodynamical methods.

When the above program of calculation was carried out, with the assumption that the most frequent collisions in the sun are the elastic nonrelativistic Coulomb collisions between electrons and protons or electrons, the results were shown to be in accord with those obtained by Weinberg. These results show that the gravitational radiation power due to thermal collisions in the sun is $P \simeq 60$ million watts, which is about the electric power needed for a small city. It is nevertheless larger than the radiation of a binary star, such as the Jupiter-Sun system, which radiates a power of 76 thousand watts.

The method of applying general relativity to calculate radiation due to collisions has also been extended to finding the total radiation of all frequencies of the spectrum without being confined to the "tail." The calculation was found to be simple and free from the cutoff process needed for estimating the "tail" radiation alone (and also needed in the quantum version of the calculation). For the case of the sun, it follows that the total radiation is only one order of magnitude larger than that of the "tail."

It is not clear yet whether such radiation has any astrophysical significance. It appears, however, that thermal collisions represent one of the most important sources of gravitational radiation in our universe.

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RELEVANT RESEARCH OF THE JOINT SERVICES ELECTRONICS PROGRAM

LT COL ROBERT B. KALISCH
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A research project, supported by AFOSR as part of the Joint Services Electronics Program and motivated by Southeast Asia Operational Requirements (SEAORs) and social urban needs, is currently under way at the Co-ordinated Science Laboratory (CSL), the University of Illinois. Under the program direction of Professors W. D. Compton and H. W. Knoebel, investigators are probing into the nature of seismic signals generated by moving vehicles.

The project has direct application to SEAORs related to new methods for the surveillance of airfield perimeters. The University of Illinois group considers local seismic detection one of the most promising techniques for detecting vehicles and identifying the vehicle type. The system consists of an array of geophones. A disturbance at each instrument is sufficient to determine the direction of motion of the source, while the character of the signal permits a determination of the origin of the disturbance.

The social urban aspects of this research had its origin in the CSL desire to assist in urban traffic control where, just as with airfield perimeters, a suitable surveillance technique is the crux of the problem. With a proper accounting for the flow of traffic, i.e., direction, speed, and numbers of vehicles, one could institute procedures for automatic control that would permit a more orderly flow of vehicles, thereby increasing the capacity of highways. The CSL approach to this problem has been primarily concerned with the detection of traffic flow with a real-time analysis of signals to give speed and direction. Seismic detection offers many advantages in that the sensors are simple, long-lived, and extremely reliable. They appear to be well matched to the system requirement.

Interpretation of the seismic data, including the pattern-recognition aspects of traffic control or airfield protection, poses difficult research problems. Nevertheless, this area probably offers the greatest promise for large-scale improvements in the present systems. Some of the most difficult current problems involve noisy data, ill-defined target signatures, terrain influences, and agricultural effects. These restrictions notwithstanding, the data available from field recordings are in many respects reminiscent of some of the early (World War II) radar data. Many of the CSL scientists believe that similar information is contained in the seismic signals. Cross-correlation of the signals with known signatures should permit identification of the source of the signal with a low probability of a false alarm.

Most of the research at CSL has been with a passive system. In the summer of 1967, measurements were made with a U.S. Bureau of Public Roads truck that was instrumented to record the normal modes of vibration of the axles. Correlations between the frequencies of the truck system and the frequencies received by the geophone array are being determined. Work continues on developing techniques for data analysis. Specifically under consideration is the influence of nonlinearities in the transmission of seismic signals as a function of terrain conditions.

Another project at CSL, similar in that it is a fundamental scientific experiment with pronounced military overtones, involves the determination of trace constituents in the upper atmosphere. This particular experiment was motivated by a desire to gain a better understanding of the physics of the upper atmosphere. This would be accomplished by a precise measurement of the absorption of sunlight at high altitudes. The absolute absorption associated with the excitation of vibrational-rotational modes of heteropolar molecules, e.g., water, carbon monoxide, nitric oxide, etc., gives a direct measure of the concentration of the molecular specie.

At CSL a technique for accurately measuring attenuations of 4 parts in 10,000 is being developed for use in determining the concentration of trace constituents in the upper atmosphere. Preliminary laboratory testing of this technique, called derivative spectroscopy, has been carried out. Laboratory measurements of the normal 5.3-micron absorptions of nitric oxide have been made in preparation for a balloon flight.

The importance of this project from a military point of view rests in its potential for the long-range detection of unusual specie in the upper atmosphere. Such a technique, when perfected, may provide a suitable remote sensor for the detection of activities which would give rise to heteropolar molecules. Nuclear detonations, missile flights and high-altitude aircraft flights are likely candidates. Conceptually, a balloon would be launched which houses a derivative spectroscope and a sun seeker. By comparison of the signature with the standard absorption pattern, one could discern unusual concentrations of particular molecules of interest.

It is unusual to have multiple motivations for research projects such as the two described above. These multiple motivations, however, provide highly relevant projects in the basic-research program.

Elimination of boundary-layer separation by slot suction

CAPT KARLHEINZ O. W. BALL
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Of extreme importance in the design of a vehicle capable of flying at hypersonic speeds is an understanding of the problem of hypersonic boundary-layer separation and the associated pressure and heat-transfer characteristics. Separation may affect the performance limits and allowable design configurations by creating undesirable shifts in loads as well as producing increases in local heat-transfer rates.

An experimental investigation was made to determine the quantitative effect of suction on a hypersonic separated laminar boundary layer. (1) The test model, shown in Figure 1, was a symmetrical front wedge of 12° half angle followed by a flap whose angle could be varied from 0 to 20° with respect to the upper surface of the wedge, thus forming a compression corner. The model simulates a lift surface followed by a control surface. In practice, the junction between the lift and control surfaces may not be sealed, thereby causing mass transfer to or from the separated region. In the investigation, suction was obtained by means of a spanwise slot of variable width between the wedge and the flap, allowing controlled natural flow from the upper high-pressure region of the corner to the relatively low-pressure region at the base of the wedge. The tests were performed at the Aerospace Research Laboratories using the 20-inch hypersonic wind tunnel at a nominal Mach number of 12. The main parameters varied in the investigation were the flap angle and the flow rate through the contoured slot. Measurements were made of the heat-transfer rate, both spanwise and chordwise pressure distribution on the two surfaces, and the flow rate through the slot.

The extent of separation was found to be extremely sensitive to suction. Schematically, this is shown in Figure 2 in terms of the wall pressure distribution as a function of the slot width, d. As the slot width is increased, the mass flow increases until a condition is obtained where the boundary layer is not separated, i.e., slot width d_3. The effect of suction is to remove the low momentum flow near the wall, thus enabling the remaining shear layer to negotiate a higher compression at reattachment.

The collapse of the separated region to the case where no separation is obtained first, i.e., the incipient separation

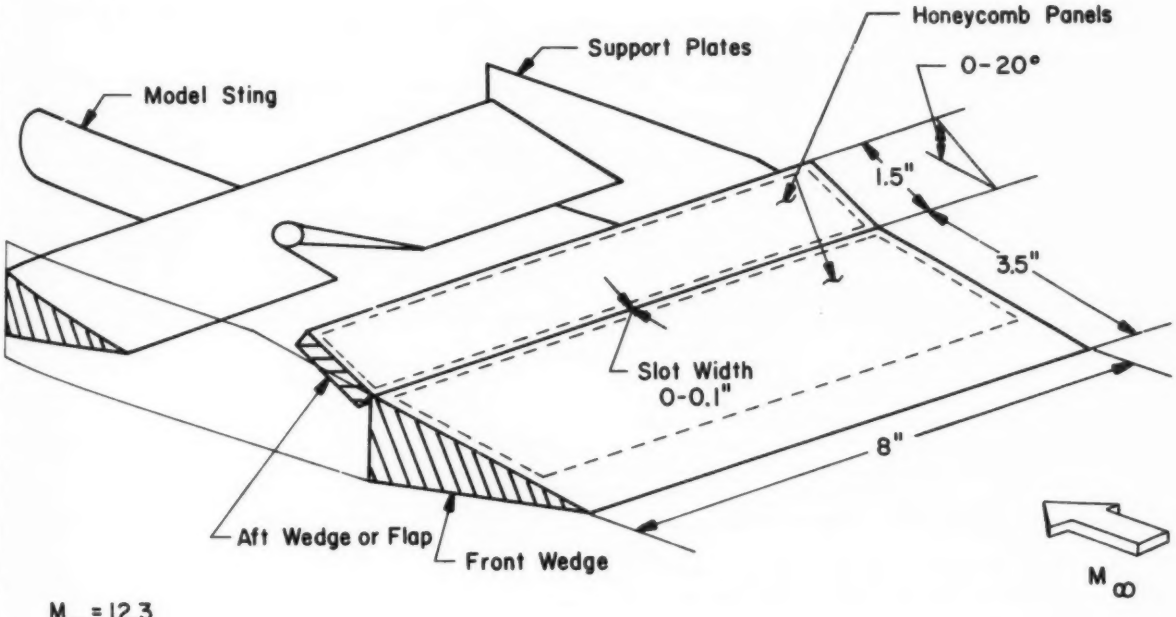

Figure 1.—Schematic of wind-tunnel model.

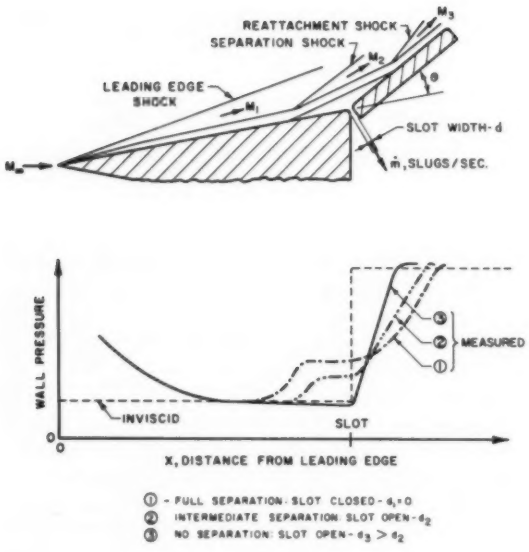

Figure 2.–Effect of slot suction on pressure distribution.

case, may be obtained independently through two geometric changes of the model:

(a) Through reducing the flap angle, Θ, until an angle, Θ_i, is reached, through which the boundary layer can turn without separating. Holden (2) has proposed, on the basis of experimental investigations, that

$$M_\infty \Theta_i \sim \bar{X}_1^{1/2}, \qquad (1)$$

where M_∞ is the free-stream Mach number, and $\bar{X}_1 = M_1^3/R_{e_1}^{1/2}$; M_1, the Mach number, and R_{e_1}, the Reynolds number upstream of the separation. The proportionality factor in the above relation has been shown to be a function of the wall-to-stagnation temperature ratio. (3)

(b) Through applying increasing surface suction, in the present case slot suction at the interface of the two surfaces, until again sufficient low energy has been removed from the boundary layer so that it is able to negotiate the turn angle, Θ, without separating.

To obtain an estimate of the slot suction required to prevent separation, the first integral of the boundary-layer momentum equation is considered.

$$\frac{d\,\Theta}{dx} + \frac{\Theta}{u_e}\frac{du_e}{dx}\left(2 + H - M_e^2\right) = \frac{\tau_w}{\rho_e u_e^2} - \frac{v_w}{u_e}, \qquad (2)$$

where

$$H = H_{tr} + (1 + H_{tr})\left(\frac{\gamma-1}{2}\right) M_e^2, \; H_{tr} = \delta^*_{tr}/\Theta_{tr},$$

v_w the suction velocity, and ρ_e the density. As a first approximation, Θ, the momentum thickness, and the transformed form factor, H_{tr}, are considered constant over the shock-boundary layer interaction at the junction of the wedge and flap. (4) Furthermore, at incipient separation, the wall shear stress, τ_w, is zero, so that Eq. (2) becomes

$$-\rho_e v_w dx = \Theta_1 \left[2 + H_{tr} + (1 + H_{tr})\left(\frac{\gamma-1}{2}\right) M_e^2 - M_e^2\right] \rho_e du_e. \qquad (3)$$

The integral of the left side of Eq. (3) is the desired mass removed, i.e.,

$$\dot{m}_s \equiv -\int_{x_1}^{x_3} \rho_e v_w \, dx.$$

Although somewhat tedious, the right side of Eq. (3) may also be integrated in terms of the Mach number.

The result is that,

$$\frac{\dot{m}_s}{\rho_{e_1} u_{e_1} \Theta_1} = f\,(M_{e_1}, M_{e_3}, H_{tr}, \rho_{e_1}, \rho_{e_3}).$$

Therefore, for known flow conditions upstream of the flap, calculations of the mass removed for incipient separation may be made as a function of the flap deflection angle.

The results of such calculation for the conditions of the experiment have been performed and are shown in Figure 3 in terms of the inviscid static pressure rise across the interaction. Agreement between theory and experiment is seen to be surprisingly good in view of the rather simple theoretical model. Extension to other experimental flow conditions is being investigated.

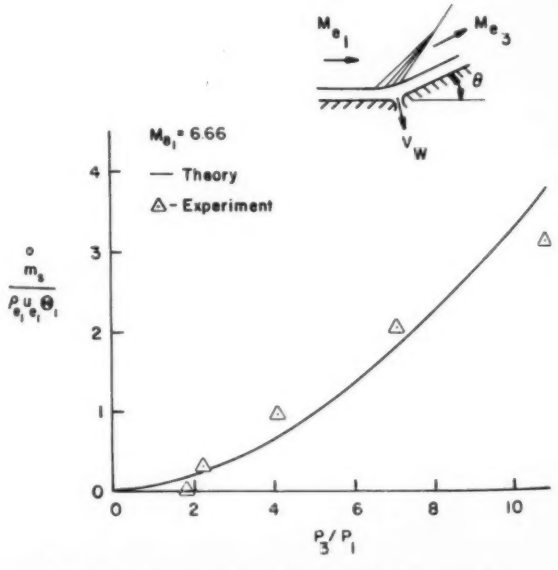

Figure 3.–Mass suction required for incipient separation.

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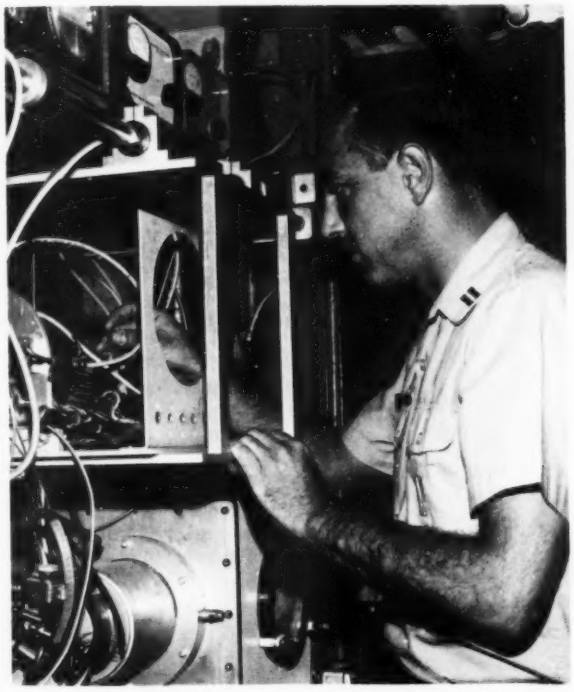


Capt Ball checking instrumentation on hypersonic wind-tunnel tests at ARL.

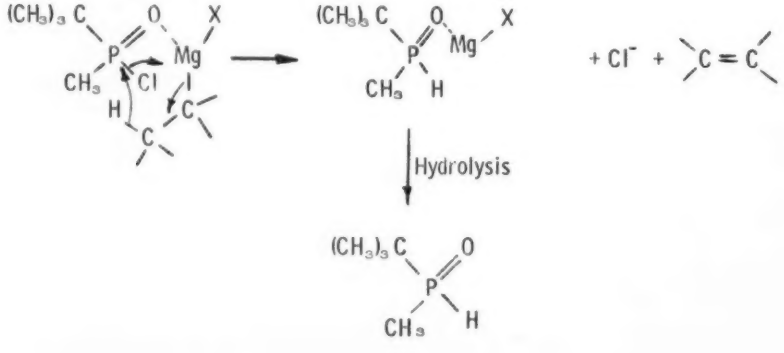
Capt Karlheinz O. W. Ball has been with the Hypersonic Research Laboratory, ARL, since October 1964. He received his B.S. in Aeronautical Engineering from the University of Alabama in June 1957 and was commissioned a second lieutenant at that time under the AFROTC program. From June 1957 to September 1958, on inactive reserve status, he worked as a theoretical aerodynamicist with the Army Ballistic Missile Agency, Huntsville, Alabama. During this same period, Capt Ball attended the Georgia Institute of Technology, from which he received his M.S. in Aeronautical Engineering in 1958. From October 1958 through August 1959, he studied at the von Karman Institute of Fluid Dynamics, Rhode-Saint-Genese, Belgium. In September 1959, he went on active duty and was assigned to the Ballistic Systems Division, AFSC, Los Angeles, California, where he served as Project Officer for Stage III of the Minuteman rocket and was awarded the Air Force Commendation Medal. He attended the University of Southern California, Los Angeles, under the Air Force Institute of Technology Program, from September 1962 through October 1964, completing the requirements for the Ph.D. in Engineering. Born in Germany, Captain Ball became a United States citizen in 1955.

ORGANOPHOSPHORUS CHEMISTRY : REACTION BETWEEN t-ALKYL GRIGNARD REAGENTS AND PHOSPHONIC-ACID CHLORIDES

MAJOR ALFRED D. BROWN, JR., Chemistry Division, FJSRL

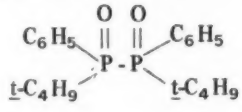
The chemistry of organophosphorus compounds occupies the attention of chemists interested in a variety of military applications. For example, phosphate esters are widely used as flame retardants. Tertiary phosphine oxides have been investigated for lubricants and fluids for high-temperature use. Some of the early nerve gases and many presently used insecticides are phosphorus-containing organic compounds.

The basic chemistry of phosphorus and its organic derivatives is under investigation in the Chemistry Division of FJSRL. One experimental study (1) recently completed by the author has shown that the reaction between phosphonic-acid chlorides [$RP(O)Cl_2$, where R = methyl, ethyl, n-butyl or phenyl] and Grignard reagents containing a large proportion of β-hydrogen atoms (t-C_4H_9MgCl, t-$C_5H_{11}MgCl$, or sec-C_4H_9MgCl) results in a variety of products in each case, the predominant product being a secondary phosphine oxide. The predominant reaction is envisaged as shown below, using methylphosphonic dichloride and t-butylmagnesium chloride as a typical example.



The total organophosphorus product mix from the reaction includes tertiary phosphine oxides formed when both chlorines are replaced by alkyl groups from the Grignard reagent, and phosphinic acids which result from the intermediate phosphinic-acid chloride or from oxidation of some of the secondary phosphine oxide.

When phenylphosphonic dichloride was used, a coupling reaction also occurred which resulted in the formation of a phosphorus-to-phosphorus bond. For example, when phenylphosphonic dichloride was reacted with t-butyl magnesium chloride, the following compound was isolated.



The detailed processes whereby these products arise are still under investigation.

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polarization of radiation from molecules excited by electron impact

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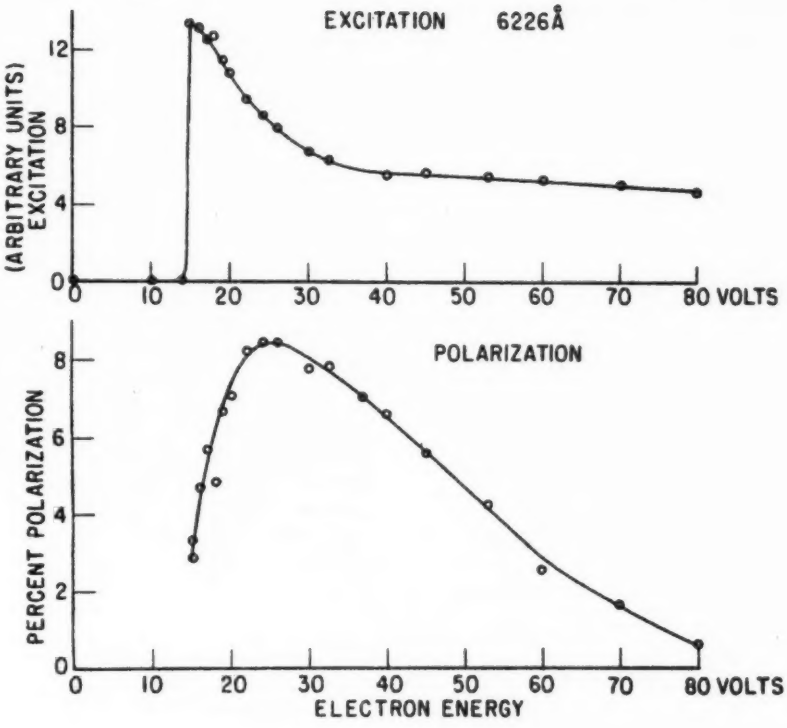
AFOSR

During recent years great interest has developed among physicists in the measurement of atomic and molecular properties by use of electron impact excitation. This has occurred because improved instrumentation has permitted the production of more nearly monoenergetic electron beams, and more sensitive and selective detection systems have given greater signal-to-noise ratios. Measurements previously impossible have become feasible, and experimenters have been industriously making them.

When atoms are excited by electron impact, the radiation emitted in the subsequent de-excitation has been found to be polarized; that is, when observed through a polaroid oriented parallel to the direction of the incident electron beam, the intensity of radiation is different from that viewed through a polaroid oriented perpendicular to the incident beam. The polarization of any single spectral line is a function of the energy of the electron beam.

Measurements of the polarization of atomic line radiation excited by electron impact have been made by several experimentalists. (1, 2) Only recently, however, has a similar polarization effect been observed in molecular line radiation. Professor Patrick Cahill and Richard Schwartz of Columbia University, under AFOSR sponsorship, together with A. Norman Jette of the Applied Physics Laboratory of Johns Hopkins University have

made measurements (3) of the polarization of the orthohydrogen emission line at λ = 6226 Angstroms, corresponding to the first rotational Q branch transition from the $^3\pi_u$ (1s 3p) $\longrightarrow$ $^3\Sigma g$ (1s 2s) electron states. Excitation and polarization curves are shown in the figure. The intensity of the excited hydrogen line is proportional to the gas pressure as well as to the electron beam current. This experiment is significant in that it provides a new and promising experimental technique for study of the fine and hyperfine structure in short-lived molecular states. These are important in energy-transfer processes such as those occurring in rocket exhausts, re-entry, and other high-energy situations.



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AFOSR

angular diameter of radio stars

One method of measuring the angular diameter of a celestial radio source employs two or more receiving antennas at known distances apart. The degree of resolution obtained depends upon the wavelength employed and the geometrical spacing of the antennas. This method is called radio interferometry and is similar in principle to that of the Michelson stellar interferometer in the visible region of the spectrum (see Figure 1). In this method, the light from the distant star is

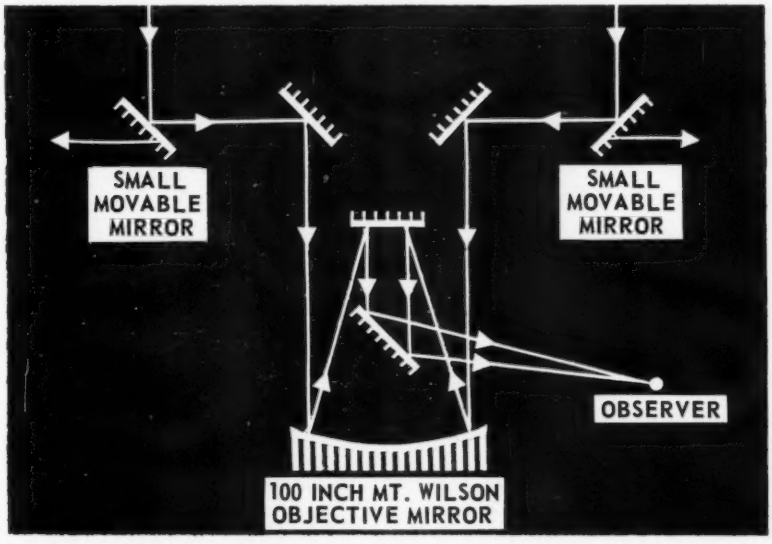

Figure 1.—A Michelson interferometer consisting of 2 movable mirrors on tracks mounted on 100-inch reflector.

reflected from two inclined mirrors at the ends of a beam mounted on the telescope tube. The light is then reflected down the axis of the telescope by two other inclined mirrors. Interference fringes are formed on the focal plane of the main mirror of the telescope. From the positions of the fringes, and the known geometry of the system, the angular diameter of the star may be calculated. The method has worked for only a few relatively close bright stars.

The radio interferometer, on the other hand, uses two or more receiving antennas (usually paraboloidal dishes) and the interference fringes are formed by combining the outputs of the two antennas (see Figure 2). Often the record is made on a magnetic tape for subsequent examination. Early interferometer experiments maintained coherence in the two signals by transmission, via cable, of a local oscillator signal to the two antennas from some central location, and by transmission of the two intermediate frequency signals from the two elements back to the central location for correlation. Still longer baselines were needed for higher angular resolution, and the cable system was no longer feasible. Microwave transmission links have replaced the cables; but this method is not suitable for baselines exceeding a few hundred kilometers because of the line-of-sight requirement in the microwave link and uncertainties in the time of transmission of the radio signals resulting from atmospheric effects.

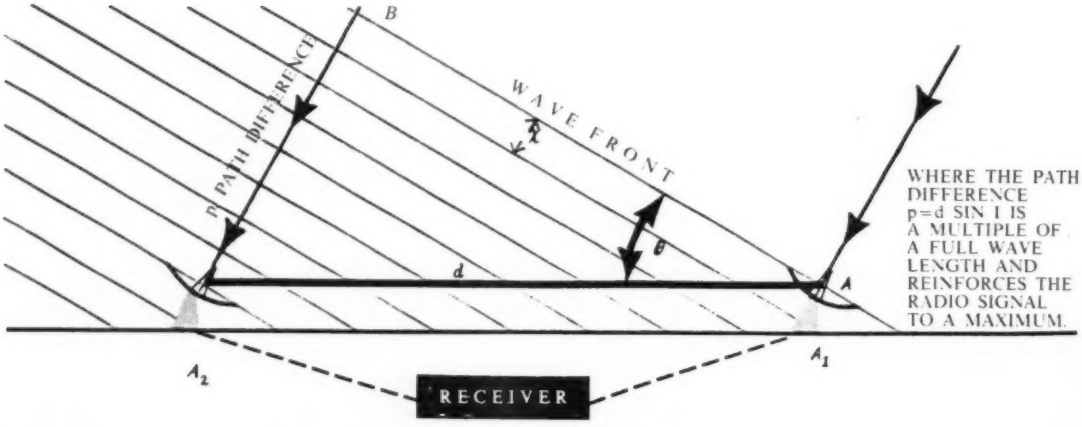

Figure 2.—Schematic diagram of a radio interferometer.

Professor M. H. Cohen of the University of California, San Diego, and collaborators C. Bare, B. G. Clark, and K. I. Kellerman, of the National Radio Astronomy Observatory, and D. L. Jauncey, of the Arecibo Ionospheric Observatory*, under AFOSR sponsorship, have employed magnetic-tape recordings for much longer baselines. (1) In this case a separate recorder was used at each antenna.

Coherent local oscillator signals were supplied at each element by two independent highly stable atomic oscillators, one at each element of the interferometer. The radio-frequency signal at 610 MHz is amplified in a two-stage rf amplifier. Both signal side bands are heterodyned to the video pass band 0-25 kHz. The 610-MHz oscillator signal is provided by a local oscillator which is phase-locked to the 122nd harmonic of the 5-MHz stabilized output of an atomic oscillator. These oscillators consist of a high-quality crystal oscillator, controlled in frequency by a comparison with the microwave line generated by atomic transitions in rubidium vapor.

The video signal at each element is then amplified and clipped. It is sampled

Operated by Cornell University under a contract sponsored by ARPA and monitored by AFOSR.

at a 9720 kHz rate, and the resulting signal recorded on high-speed digital magnetic tape. The sampling rate is controlled by the atomic frequency standard which also drives a digital clock set up by comparison with the Loran C 100 kHz VLF transmission. In making observations reported here, each length of tape provided 200 seconds of data, totaling approximately 1.4×10^8 bits.

The tapes from the two stations were then brought together in a digital computer, and an interferometer fringe frequency determined.

A test of the system was provided by operation as an interferometer between the telescope at the National Radio Astronomical Observatory in Green Bank, West Virginia, and the Maryland Point Observatory of the Naval Research Laboratory. This provided an east-west baseline of about 461,000 wavelengths at 610 MHz. Observations of 4 radio sources suspected of having small angular diameters were made on 8-9 May 1967. All were found to have angular diameters of a few tenths of a second of arc. The observations are continuing on other sources.

The method employed may also be used to determine the distances between the elements of the interferometer when it is known that the radio source under observation has a small angular diameter, and is thus potentially capable of measuring distance between points on the earth to the accuracy of a few decimeters, or possibly less when efforts at refining the apparatus and methods are successful. The method is particularly useful for distances so great that triangulation loses accuracy. Thus, it will be useful in geodesy and, over a period of time, in obtaining data on the movements of land masses on the surface of the earth.

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Research on Hypersonic Stability Derivatives in Pitch for Blunted Slender Cones

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Hypersonic Research Laboratory
ARL

The purpose of this note is to summarize briefly ARL's recent research work in the field of hypersonic stability derivatives $C_{m_q} + C_{m_{\dot{\alpha}}}$ and C_{m_z} for spherically blunted slender cones at hypersonic Mach numbers. Experiments were conducted in the ARL 20-inch hypersonic wind tunnel, which is a free-jet blow-down tunnel, supplied by dried, filtered and heated compressed air. The contoured nozzle has interchangeable throat sections for Mach number variation. Typical tunnel data are as follows:

Total pressure	$p_t = 1500$ psi
Total temperature	$T_t = 2000°$ R
Free stream Mach number	$M_\infty = 14$
Free-stream static pressure	$p_\infty = .0034$ psi
Free-stream dynamic pressure	$q_\infty = .465$ psi
Free-stream temperature	$T_\infty = 52.5°$ R
Free-stream velocity	$V_\infty = 4965$ ft/sec
Free-stream Reynolds number	$Re_\infty = 6 \times 10^5$ per foot

The jet core is approximately 10 inches wide, and the Mach-number variation along and across the core is less than $\pm 1\%$. Only a fraction of the available flow duration of 2 minutes is used for dynamic tests. From what is known by various

calibration and liquefaction studies, the air in the test section is considered supersaturated but not liquefied. (1, 2)

When dynamic testing was planned, the free-oscillation technique was chosen, where the sting-strut supported model is free to perform planar pitching oscillations with small amplitudes about an arbitrarily selected trim angle of attack, α_T. Beryllium-copper flexures with various spring constants served as the elastic link between model and support system giving a range of reduced frequencies, $\omega\ell/V_\infty$ from .01 to .04. These flexures were specifically designed for dynamic test in the low-density flow of the ARL wind tunnel, and excelled by virtue of a very small energy dissipation due to internal friction. In vacuum and without wind, 3,000 to 5,000 cycles, depending on shear-stress amplitude, were observed before the amplitude of an oscillating model decayed to one half of its original values. Frequency and amplitude decay were measured, both for "wind on" and "wind off" conditions. From these data and from known physical model constants and flow properties, the static and dynamic stability derivatives C_{m_α} and $C_{m_q} + C_{m_{\dot\alpha}}$ are deduced. For more details, see (3, 4).

With the first experiment no specific research objective was pursued besides gaining experience in dynamic stability testing in the low-density flow of the ARL tunnel. Therefore, an available cone model was used which happened to have a small cone half angle, $\Theta_c = 5.6°$, and a nose-to-base radius ratio, $\eta = r_N/r_B = .176$. Thanks to this configuration, two interesting problems were encountered. First, it was found that the model was dynamically stable at zero and at negative trim angles of attack, but erratically unstable at positive angles. This anomaly was explained by a support interference to which cones of small angles are especially susceptible. The interference was eliminated by adding fairings to the strut and by using the greatest sting length compatible with the layout of the test cabin. In addition, the base pressure was monitored during all future tests. The other result, which at that time seemed peculiar, was the agreement of Newtonian impact predictions with the measured static derivatives but not with the measured damping derivatives, while at about the same time AEDC found just the opposite trend for a blunted 10° cone. It was concluded that any agreement of one or the other derivatives with Newtonian values must be accidental because the cone-surface pressure distribution deviates considerably from Newtonian impact values when $\Theta_c \sqrt{x/d_{Nose}} \lesssim .8$. However, it was considered worthwhile to learn more about the nose effect on the hypersonic stability derivatives of spherically blunted slender cones.

A tangent-cone analysis was based on the empirical blunt cone surface pressure correlation for zero lift, as presented by Griffith and Lewis (5) in the form of the pressure function $n = C_p/2\Theta_c^2$ versus Cheng's distance parameter, $(\Theta_c^2/\sqrt{\epsilon\, C_{D_{Nose}}})\,(x/d_{Nose})$. For convenience, Cheng's parameter was modified to $\Theta_c\sqrt{x/d_{Nose}}$, using $C_{D_{Nose}} = 1$ and $\gamma = 1.4$. Then,

$$\text{for } \alpha = 0, \quad C_p = 2\Theta_c^2\, n$$

and

$$\text{for } \alpha > 0, \quad C_p = 2(\Theta_c \pm \alpha_{eff})^2 \left(n \pm \frac{\partial n}{\partial \Theta_c}\,\alpha_{eff}\right)$$

where the + and - signs stand for the bottom and top ray of the cone model, respectively, and α_{eff} may be a small static angle of attack, α, or a pitch induced angle of attack, α_j, or both together. The assumption of a sinusoidal variation of the pressure coefficient from bottom to top allows the integration of the normal force components around the cone in closed form, giving the elemental normal force coefficient referred to the base area

$$dC_N = 4\alpha_{eff}\left[\frac{x}{\ell}(1-\eta)^2 + \eta(1-\eta)\right]\left(n + \tfrac{1}{2}\,\Theta_c\frac{\partial n}{\partial \Theta_c}\right) d\left(\frac{x}{\ell}\right)$$

The pitching-moment coefficient for a specific moment center can now easily be obtained as a function of α_{eff} and the partial derivatives with respect to α, and the nondimensional pitching velocity, $q\ell/V_\infty$, can be determined. (6)

If n is considered a universal function of the modified Cheng parameter, then $\theta_c\ (\partial n/\partial\theta_c)$ is a universal function of the same parameter also. Rewriting $\theta_c\ \sqrt{x/d_{Nose}} = C\ \sqrt{x/\ell}$, where $C = \left[\theta_c\ (1-\eta)/2\eta\right]^{1/2}$, it is seen that the distribution of the term $\left(n + \frac{1}{2}\ \theta_c\ (\partial n/\partial\theta_c)\right)$ from nose to base is identical for all members of a cone family with different cone angles and bluntness ratios, but defined by one value of C. The parameter C, therefore, is considered to correlate the effects of nose bluntness and cone angle on the stability derivatives with a grain of salt introduced by the term $\left[x/\ell\ (1-\eta)^2 + \eta\ (1-\eta)\right]$ which is not identical for the individual members of one family but has a weak effect only for values of η not too large.

The 5.6° cone model was now investigated with six interchangeable noses, η from .004 to .3 to cover a range of C values from 3.5 to .34, respectively. The pivot point was fixed at a distance of 2.04 base diameter in front of the base. The center-of-gravity (CG) position with respect to the shoulder of the nose varied accordingly, $x_{cg}/\ell = 1 - 4.08\ \theta_c/(1-\eta)$. Dynamic wind tunnel tests were made for various reduced frequencies and trim angles of attack. (7) Fig. 1 shows the results for zero trim angle, indicating that the spherical nose blunting has a pronounced

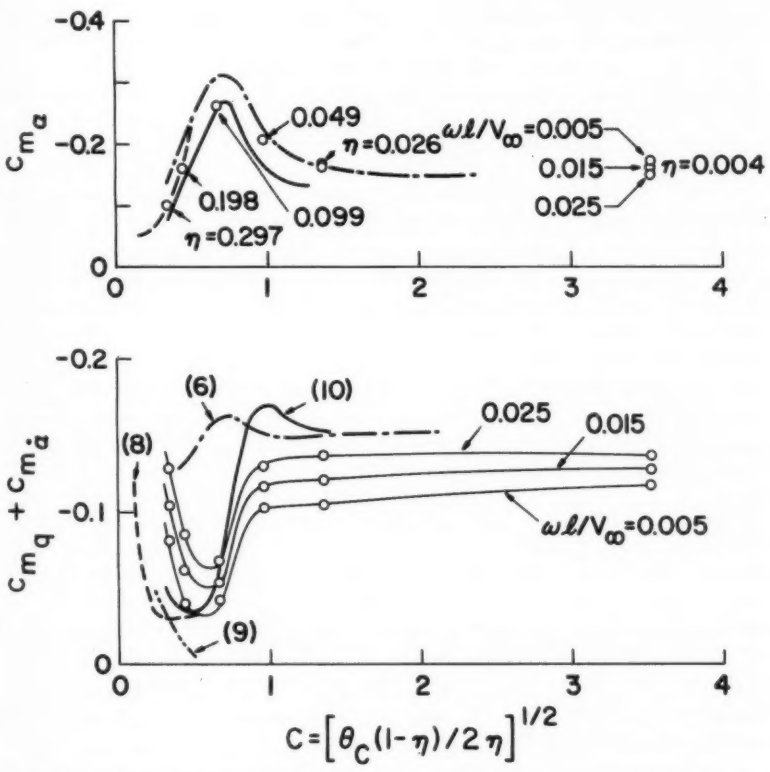

Figure 1.—Stability derivatives for a 5.6° cone with various nose-bluntness ratios η. x_{cg}/ℓ = 1-4.08 $\theta_c/(1-\eta)$, $\alpha_T = 0$. —◯—ARL, Mach-14 wind-tunnel data, $Re_\infty\ell$ = .4 to .6 x 10^6

(6) tangent-cone analysis, C_{m_q} with $\alpha_i = q(x-x_{cg})/V_\infty$, $C_{m_{\dot\alpha}} = 0$

(8) blast-wave analysis for $C \leqq .5$, $C_{m_{\dot\alpha}} = 0$

(9) tangent-cone analysis, C_{m_q} with $\alpha_i = q(x/2-x_{cg})/V_\infty$, $C_{m_{\dot\alpha}} = 0$

(10) GE unsteady flow field theory.

effect on both derivatives if C decreases below the value of one. The semiempirical tangent cone analysis, sketched above, adequately predicts C_{m_α} over the whole range of C values investigated, but did not predict the measured severe breakdown of the damping derivatives. A distinct frequency effect on the damping derivatives was observed, but was not further analyzed. It may be noted that a standard 10° cone (η = .0167, C = 2.27) investigated at Mach 12 and 14 did not show such a frequency effect over the range $\omega\ell/V_\infty$ = .013 to .039 and for amplitudes from .5 to 6.0 degrees. (4)

It was the specific purpose of B. P. Quinn's blast-wave analysis (8) to furnish more analytical information in the range of low C values. This analysis is founded on Chernyi's blast-wave-piston analogy. For steady axial flow conditions, Quinn approximated the equations governing the shock shape and the surface pressure by a power series which for $C \lesssim .5$ converged sufficiently to give a pressure distribution over the cone surface in very good agreement with Chernyi's numerical solution. The unsteady case of small amplitude oscillations about zero trim angle is treated by perturbing the piston radius in analogy to the oscillating cone with the pivot axis through the nose. The corresponding perturbations of shock shape and surface pressure are derived. The pressure perturbation was found to have one component in phase with the angular displacement and another component in phase with the displacement velocity. From these two perturbation pressure components the static and dynamic stability derivatives C_{N_α}, $C_{m_{\alpha_o}}$, $C_{N_{q_o}}$, and $C_{m_{q_o}}$ are derived for the moment center at the nose. With Tobak's axis-transfer equation, the derivatives are determined for any CG location. The results of this analysis evaluated for the 5.6° cone are included in Fig. 1 and show fair agreement with the measurements. Even so the blast-wave analysis is for an infinite large hypersonic similarity parameter, while a value of $M_\infty \theta_c$ = 1.4 applies only to the measurements. The important feature of Quinn's analysis is that it relates the severe loss in pitch damping for C values around .5 to the blast-wave-type flow produced by the high-drag nose.

J. T. Clay (9) wondered why the tangent-cone analysis adequately predicts C_{m_α} over the whole range of bluntness ratios investigated, but did not describe the observed breakdown of the damping derivatives. He conjectured that the pitch-induced local angles of attack α_i may be different in the blast-wave regime, $C \lesssim .5$ and in the region defined by $C \gtrsim 1.0$, where the flow over the main portion of the model has a conical character. With an engineering approximation, based on the physics of the blast-wave flow, he concluded that, for a pure pitching motion with the velocity q, the induced angle of attack $\alpha_i = q\,(x/2 - x_{cg})/V_\infty$ should be representative for $C \lesssim .5$, while the usual value of $\alpha_i = q\,(x - x_{cg})/V_\infty$ should be adequate for $C \gtrsim 1.0$ only. The damping derivatives calculated with the tangent-cone method agree trendwise with the measurements when these two types of pitch-induced local angles of attack are used, leaving a gap, however, from $C \sim .5$ to 1.0, Fig. 1. Clay also used a program designed by the General Electric Company for the IBM computer 7094 to compare ARL's hypersonic wind-tunnel measurements with GE's unsteady flow field theory for spherically blunted cones at zero trim. This is an inviscid numerical solution of the laws of conservation of mass, momentum, and energy within the shock layer. With a perturbation technique, the pressure derivatives corresponding to small amplitude oscillations about zero trim are obtained. (10) The numerical results for C_{m_α} and $C_{m_q} + C_{m_{\dot\alpha}}$ are included in Fig. 1 and show good agreement with the test results. Especially, the breakdown of the damping derivatives is well predicted by GE's inviscid unsteady flow field solution.

Fig. 2 shows ARL's wind-tunnel results (9) for a 10° cone at Mach 14, compared with the various analyses described above. The trend of the derivatives is very similar to what was experienced with the 5.6° cone. Again, a peak value for C_{m_α} was found for $C \approx .7$, and the damping derivatives are severely reduced when C drops below the value of 1 and reach a minimum at $C \approx .6$. Experiments and theories are in satisfactory agreement.

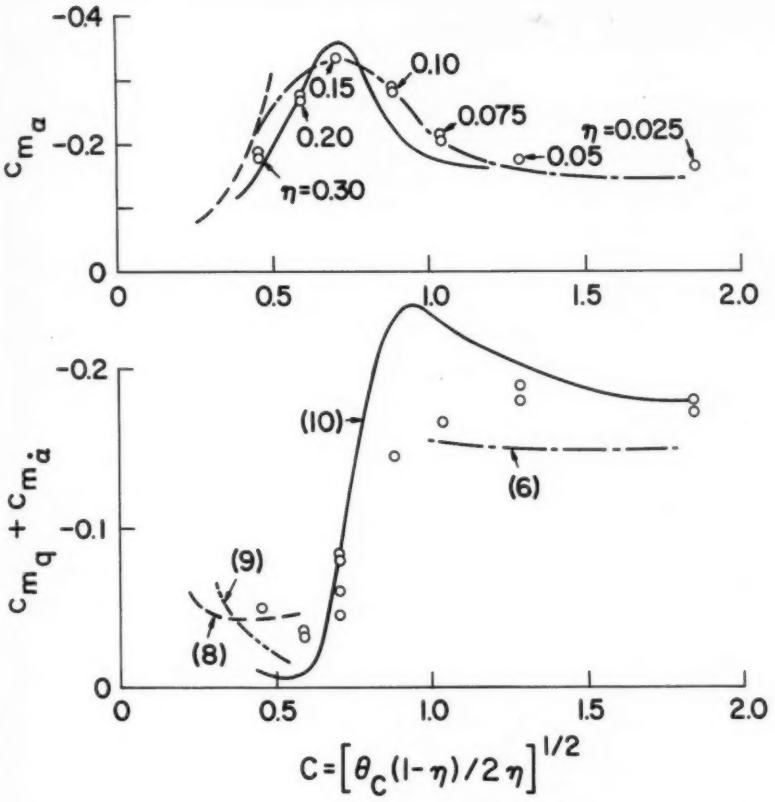

Figure 2.—Stability derivatives for a 10° cone with various bluntness ratios η. x_{cg}/ℓ = 1-2.22 $\theta_c/(1-\eta)$, α_T = 0. —◯—ARL, Mach-14 wind-tunnel data, $Re_{\infty\ell}$ = .4 to .55 x 10^6, $\omega\ell/V_\infty$ = .015 to .019

(6) tangent-cone analysis, C_{m_q} with $\alpha_i = q(x-x_{cg})/V_\infty$, $C_{m_{\dot\alpha}} = 0$

(8) Blast-wave analysis for $C \leqq .5$, $C_{m_{\dot\alpha}} = 0$

(9) tangent-cone analysis, C_{m_q} with $\alpha_i = q(x/2-x_{cg})/V_\infty$, $C_{m_{\dot\alpha}} = 0$

(10) GE unsteady flow field theory.

Clay extended the numerical study of nose-bluntness effects with the GE program over a range of Mach numbers (M = 8 to 20), cone angles (5.6° to 15°), and various CG locations. He found that the earlier derived parameter, C, indeed correlates well the effect of Θ_c and τ in all cases studied, and that the detrimental effect of nose blunting on the damping derivatives is less severe for smaller Mach numbers. Wind-tunnel tests by the Jet Propulsion Laboratory (11) at Mach 6 and 8, together with the ARL tests at Mach 14, confirm GE's Mach-number trend which levels off for $M \gtrsim 15$. (9)

So far, the case of zero trim angle of attack has been discussed only. Some wind-tunnel experiments were made with the 5.6° cone at different trim angles up to 10°. (7) Fig. 3 shows the result. C_{m_α} does not vary with α_T when the nose is nearly sharp. Blunting of the nose, however, introduces drastic nonlinearities with trim angle. $C_{m_q} + C_{m_{\dot\alpha}}$ for the nearly pointed cone model remains constant up to a trim angle of approximately the cone half angle, then rises and levels out again. This trend was found by other investigators also. Again, drastic changes with trim angle are produced by nose blunting. It may be concluded that the observed variations of both derivatives with trim angle and nose bluntness look somewhat confusing, and that an effort should be made to interpret the results, at least qualitatively.

Consider the most windward bottom ray of a blunt cone defined by the

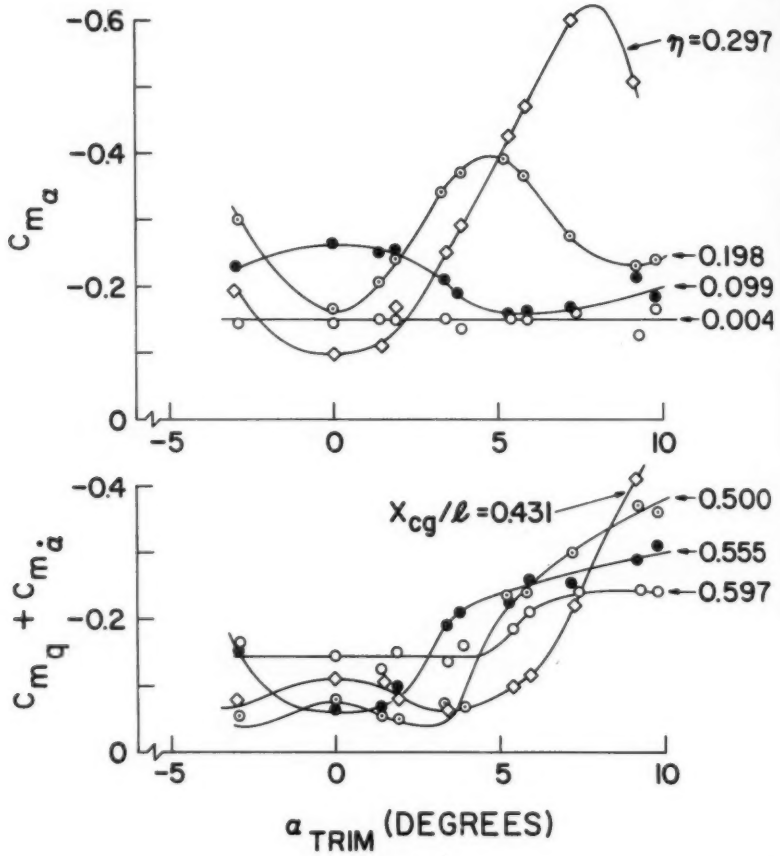

Figure 3.–Stability derivatives for a 5.6° cone with various bluntness ratios η versus trim angle of attack. ARL Mach-14 wind-tunnel data.

parameter $C = \left[\Theta_c (1-\eta)/2\eta\right]^{1/2}$ at $\alpha_T > 0$. Within the approximation of the tangent-cone concept, and disregarding cross-flow effects, the distribution of the pressure coefficient C_p over this ray is the same as over a cone defined by $C' = \left[\Theta' (1-\eta')/2\eta'\right]^{1/2}$ in axial flow. Here, $\Theta' = \Theta_c + \alpha_T$ and $\eta' = r_N/r_B'$ where the effective base radius $r_B' = r_B \Theta'/\Theta_c$ so that $\eta' = \eta\Theta_c/\Theta'$. Note that $C' > C$. The C_p values over the bottom ray are larger than over the top ray, and the pitching-moment derivatives are mainly due to pressure perturbations along the bottom ray. Then, it may be concluded, that the derivatives change with trim angle trendwise in the same manner as they do in axial flow when the parameter C is increased to C′.

A cross plot in Fig. 3 through $\alpha_T = 0$ corresponds to what is shown in Fig. 1. From this figure it is seen that C_{m_α} has a peak value for $\eta \approx .1$. An increase of the corresponding C value in simulation of an increasing trim angle reduces C_{m_α} toward the sharp-cone value. The static derivatives for $\eta \sim .2$ and .3 are beyond the peak value, and an increase of the corresponding C parameters brings C_{m_α} up to the peak at first and then down toward the sharp-cone values. This is, indeed, the trend of C_{m_α} with trim angle shown in Fig. 3. The same consideration holds for the damping derivatives. In Fig. 1, at $\alpha = 0$, $C_{m_q} + C_{m_{\dot\alpha}}$ is close to the minimum value for the model with a bluntness ratio $\eta \approx .1$. An increase of the corresponding C parameter brings the damping derivatives immediately out of the

"blast-wave ditch." As for $\eta \sim .2$ and .3, the damping derivatives are beyond the minimum value. Increasing the corresponding C parameter in simulation of an increasing trim angle brings the derivatives down into the "ditch" at first, and then out. Again, the same trend is seen in Fig. 3 as a result of increasing trim angles.

In Fig. 4, the derivatives measured at various trim angles are plotted versus the parameter C′; and it is seen that this parameter brings some order into their variations with trim angle of attack. No further attempt was made to correlate the magnitude of the derivatives with trim angle, especially in view of the variation of the CG location with nose bluntness.

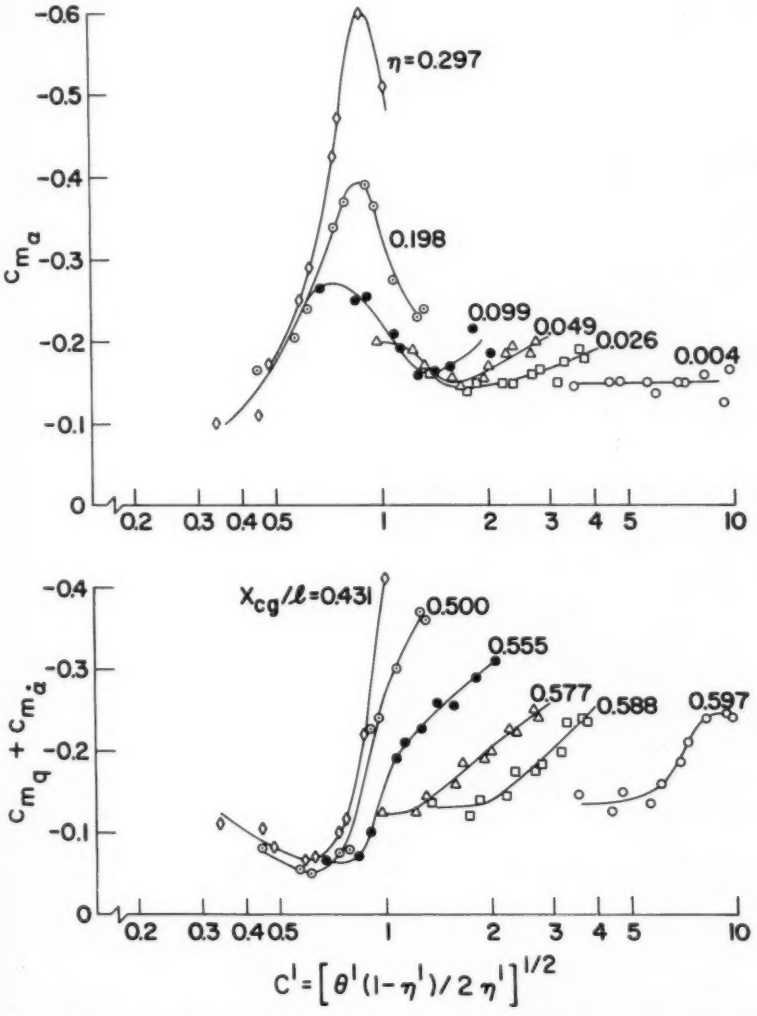

Figure 4.–Stability derivatives from Fig. 3 versus cone angle-bluntness ratio-trim angle correlation parameter C′. $\theta' = \theta_c + \alpha_T$, $\eta' = \eta\,\theta_c/\theta'$.

In summary, it may be stated that spherical nose blunting of slender cones has a pronounced effect on hypersonic static and dynamic stability derivatives in pitch if the parameter $C = \left[\Theta_c\,(1-\eta)/2\eta\right]^{1/2}$ grows less than 1. Mach-14 wind-tunnel tests and various analyses are in satisfactory agreement for zero trim angle of attack. Minimum values for the damping derivatives are observed for $C \approx .6$. The breakdown of $C_{m_q} + C_{m_{\dot{\alpha}}}$ to a fraction of the sharp-cone values is a

typical high Mach-number effect. Wind tunnels should have at least Mach-14 capability to seize correctly the severeness of the breakdown. Nose blunting also introduces drastic nonlinearities of both static and dynamic derivatives with trim angle of attack.

Dynamic instability was not observed when the motion was restricted to planar oscillations about trim. However, because of the small values of the damping moments observed, the effect of the Magnus moments becomes important for additional freedom in roll and yaw. For instance, the dynamic stability requirement

$$1 > \frac{p}{\omega}\left(\frac{I_x}{2I} + \frac{C_{m_{p_\beta}}}{C_{m_q} + C_{m_{\dot{\alpha}}}}\right) > -1$$

is derived from the linearized moment equations for an axisymmetric vehicle which has freedom to roll, pitch and yaw. In view of the small pitch damping moments resulting from nose blunting and for roll rates p comparable with the pitch frequency ω, it is seen that only small Magnus terms can be tolerated to insure dynamic stability. The study of hypersonic Magnus moments, therefore, is a worthwhile future research objective.

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NOMENCLATURE

C_m	= pitching moment/$q_\infty S \ell$	q_∞	= free-stream dynamic pressure
C_{m_α}	= $\partial C_m/\partial\alpha$	S	= base area
$C_{m_q} + C_{m_{\dot{\alpha}}}$	= $\partial C_m/\partial(q\ell/V_\infty) + \partial C_m/\partial(\dot{\alpha}\ell/V_\infty)$	V_∞	= tunnel flow velocity
$C_{m_{p_\beta}}$	= $\partial/\partial\beta\left(\partial C_m/\partial(p\ell/V_\infty)\right)$	x_{cg}	= distance from shoulder of nose to CG
d	= base diameter	α	= angle of attack
I	= moment of inertia	β	= angle of side slip
ℓ	= length from shoulder of nose to base	Θ_c	= cone half angle
p	= roll rate	η	= r_N/r_B = nose-bluntness ratio
q	= pitching velocity	ω	= circular pitching frequency

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